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Dynamic Modeling of Nonmedical Opioid Initiation: Epidemic and Access

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We report development of a systems level dynamic model of initiation and nonmedical use of pharmaceutical opioids in the US. The model calibrated to 1995-2005 National Survey of Drug Use and Health (NSDUH) data, predicts 2006-2011 data well. Preliminary findings indicate that interventions which reduce the perceived attractiveness of opioids for recreational use may be able to reduce initiation and nonmedical use most significantly, while supply restriction effected through drug take back days and prescribing changes may have more modest effects. We argue that system dynamics is an effective approach for evaluating potential interventions to this complex system where the use of pharmaceutical opioids to treat pain is fraught with undesirable distal outcomes.

Background

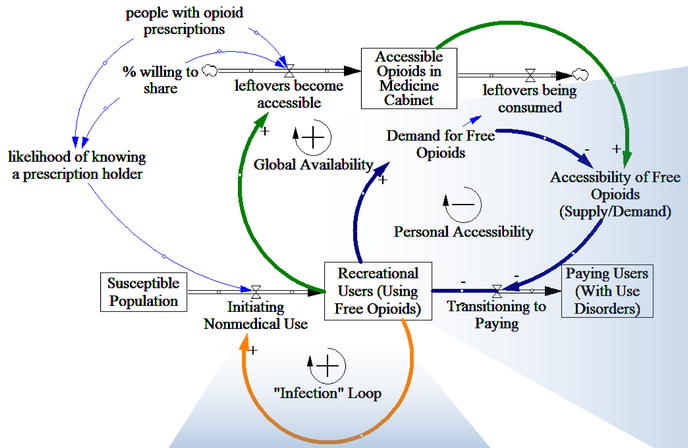
The number of overdose deaths involving opioids tripled between 1999 and 2006 in the US, rising to 14,800 in 2008 (Warner et al. 2011). As evidenced by the high fraction of opioid overdose decedents without prescriptions (Hall et al. 2008), nonmedical use of pharmaceutical opioids plays a significant role in the prevalence of overdose deaths. Leftover opioid prescriptions are likely involved in much of this diversion (Compton and Volkow 2006). Studies suggest that there is a large reservoir of unused opioids stored in homes (Bates et al. 2011; Gilson 2012), and the high fraction of individuals receiving drugs for free from friends and family as reported in the NSDUH (SAMHSA 2012) is likely to be strongly correlated with the size of this reservoir.

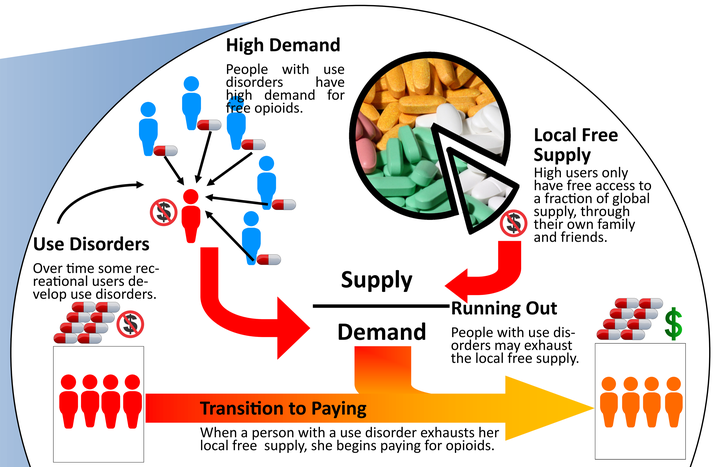
Methods

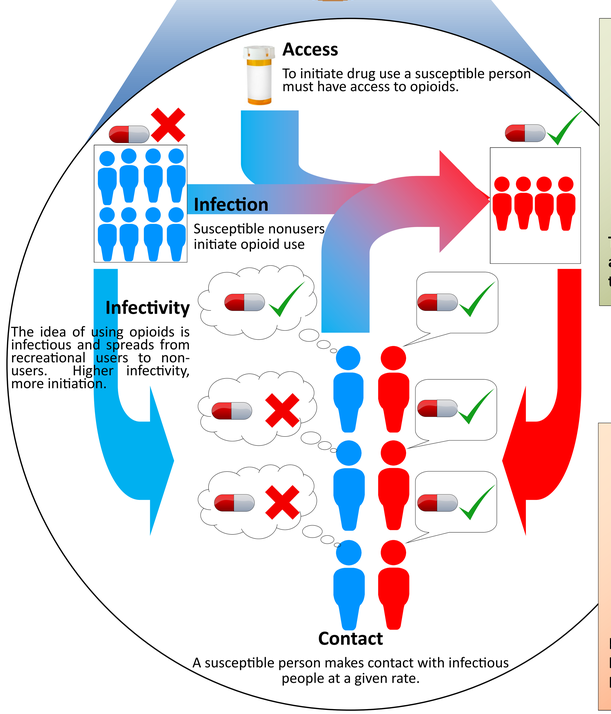
Drawing from empirical data and a panel of experts, a system dynamics simulation was developed to reproduce historical trends in nonmedical use of pharmaceutical opioids in the United States. Data to support assumptions and model parameters were drawn from publicly available sources in the literature. Data on initiation and nonmedical use were obtained from the NSDUH for the years 1995 to 2011. System dynamics is a simulation method in which complex relationships and feedback loops are specified and mathematically formalized. The resultant set of differential equations was calibrated to replicate opioid use data from 1995-2005, used to predict behavior from 2006 to 2011, and to evaluate policy interventions.

Results

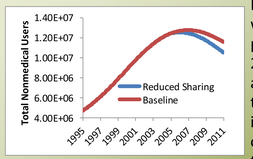
The model contains 5 state variables, 13 exogenous parameter variables, 21 endogenous (calculated) parameters and 10 rates of change. Three principal feedback loops (a peer initiation epidemic loop, a global availability loop, and a personal accessibility loop) contribute to the nonlinear growth patterns in nonmedical opioid initiation and use. Peer initiation is modeled as the infection of a susceptible population by peers. Global availability of opioids for nonmedical use depends on the number of current opioid users and how much free leftover medicine they obtain from prescription holders. When availability diminishes, reduced personal accessibility requires transitions to paying for opioids. Compelling susceptible non-users to resist initiation (e.g. Gosin et al. 2003) was more effective in reducing nonmedical use than compelling prescription holders not to share their medicines (e.g. FDA 2013), and reducing global availability through prescription take back events (e.g. DEA 2012).







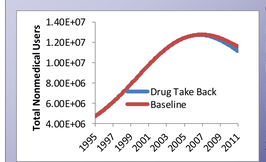
Intervention: Reduce % Willing to Share



Reducing people willing to share prescriptions by 25% affects global supply **and** initiation by reducing access to opioids for new initiates.

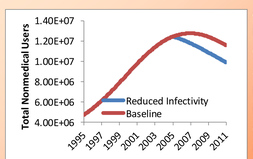
The effect on initiation is mitigated because initiates are likely to know several prescription holders, but then amplified by positive feedback.

Intervention: Reduce Global Supply



Global supply is reduced through DEA Take Back Days. Supply is reduced by 100 million dosage units per year. Supply constriction causes recreational users to quit sooner and people with use disorders to start paying sooner. **The effect is small because global supply remains plentiful.**

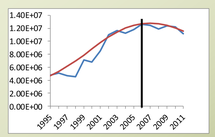
Intervention: Reduce Infectivity



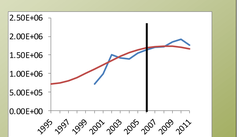
A 25% decrease in the infectivity of opioid use results in a dramatic decrease in the number of nonmedical users. This is largely due to positive feedback.

Lower initiation —> Fewer recreational users —> Fewer contacts with nonusers —> Lower initiation.

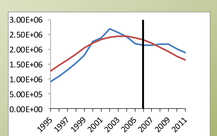
Calibration and Prediction



Total Nonmedical Users



People with Use Disorder



Total Initiates

Blue trace shows empirical data, red trace shows model output. Prediction errors (MAPE):

. Nonmedical Users = 3.76%

. Initiates = 6.13%

. Use Disorder = 3.47%

Discussion

The relative impact of the three interventions simulated can not be explained by feedback alone as all three interventions are amplified by positive feedback loops. The infectivity intervention reduces the initiate rate by 25%, and this reduction is immediately amplified by feedback. The willingness to share intervention impacts both the infection loop and the global availability loop, but the 25% reduction is indirect. Reducing by 25% the number of people who are willing to share prescriptions only reduces the likelihood that a potential initiator will know at least one prescription holder by a small percentage. This likelihood is based on a binomial distribution and is large when a large fraction of the population has prescriptions. So the impact on initiation and global supply is much smaller than 25%. This smaller reduction is amplified by positive feedback, which suggests that limiting sharing is an intervention with leverage. Supply reduction through prescription take back days is the least effective strategy primarily because the reservoir of leftover medicines is so large that the reduction implemented did not cause the system to be supply constrained.

Conclusion

The current model offers a formalized model of a common pathway to nonmedical opioid initiation and provides a tool for comparing the impact of multiple policy interventions. System dynamics modeling brings insights on the global dynamics of nonmedical opioid use and can be used to inform policy interventions to ameliorate the associated public health problems.

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